3-D Seismic Survey Study of Faults System in Balad Oil Field – Center of Iraq

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Abstract
3D seismic reflection structural study of (250) km² of Balad Oil field located in central part of Iraq within Salah Al-din province (Balad area) was carried out.
Faults were picked using instantaneous phase attribute of seismic sections and variance attribute of seismic time slices across 3D seismic volume.
A Listric growth normal fault is affecting the succession of Cretaceous Formation and cut by strike slip fault. In addition, minor normal faults (Dendritic and tension faults) are developed on the listric normal growth fault. As a result, a major graben is separated by Strike slip fault into two parts (north and south parts) and trend in NW-SE direction.

Keywords: 3-D Seismic Survey, Faults System

دراسة المسح الزلزالي ثلاثي الابعاد لنظام الصدوع في حقل بلد النفطي وسط العراق

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الخلاصة:
أن هذا البحث يمثل دراسة تركيبية بأستخدام طريقة المسح الزلزالي الأنعكاسي بالأبعاد الثلاثة في منطقة مساحتها 250 كم² لحقل بلد النفطي الذي يقع في وسط العراق ضمن محافظة صلاح الدين (منطقة بلد).
التقطت الصدوع المؤثرة على العواكس الملتقطة وفسرت بأستخدام تطبيقات الملامح الزلزالية (الطور الآني كمقاطع زلزالية والتغاير الجانبي كشرائح زمنية) للمكعب الزلزالي.
أثر صدع من نوع الأعتيادي المنحني المتنامي الذي يتزامن نشوءه مع زيادة سمك الرواسب على صخور العصر الكريتاسي والطبقات التي تقع أسفله وقد قطع بواسطة صدع أنزلاقي، أضافة الى وجود الصدوع الشجرية والشدية التي نمت وتطورت على الفالق الأعتيادي المنحني المتنامي. أظهرت النتائج وجود صدع خسفي رئيسي (طية مقعرة متصدعة) وقد فصلت بواسطة صدع أنزلاقي الى جزئين (شمالي وجنوبي) أتجاه شمال غرب–جنوب شرق.

Introduction

The seismic reflection exploration method passed through numerous development stages from mid last century to the present time including the field survey, data processing & interpretation. 3-D

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seismic survey gives huge amount of the seismic data which permit a better interpretation and gives detailed picture to the subsurface geology [1].

The current research is structural interpretation study of the seismic reflection data for the Balad 3D seismic survey which is the first 3D seismic survey carried out in Iraq by the Iraqi seismic 3D crew and Halliburton Corporation. Data acquisition began in 1990 and was completed in 1992.

Location of the study area

The Balad oil field is located in the middle of Iraq along the Tigris River within Salah Al-din province approximately (60-70Km) to the north of Baghdad as shown in the figure-1a & b.

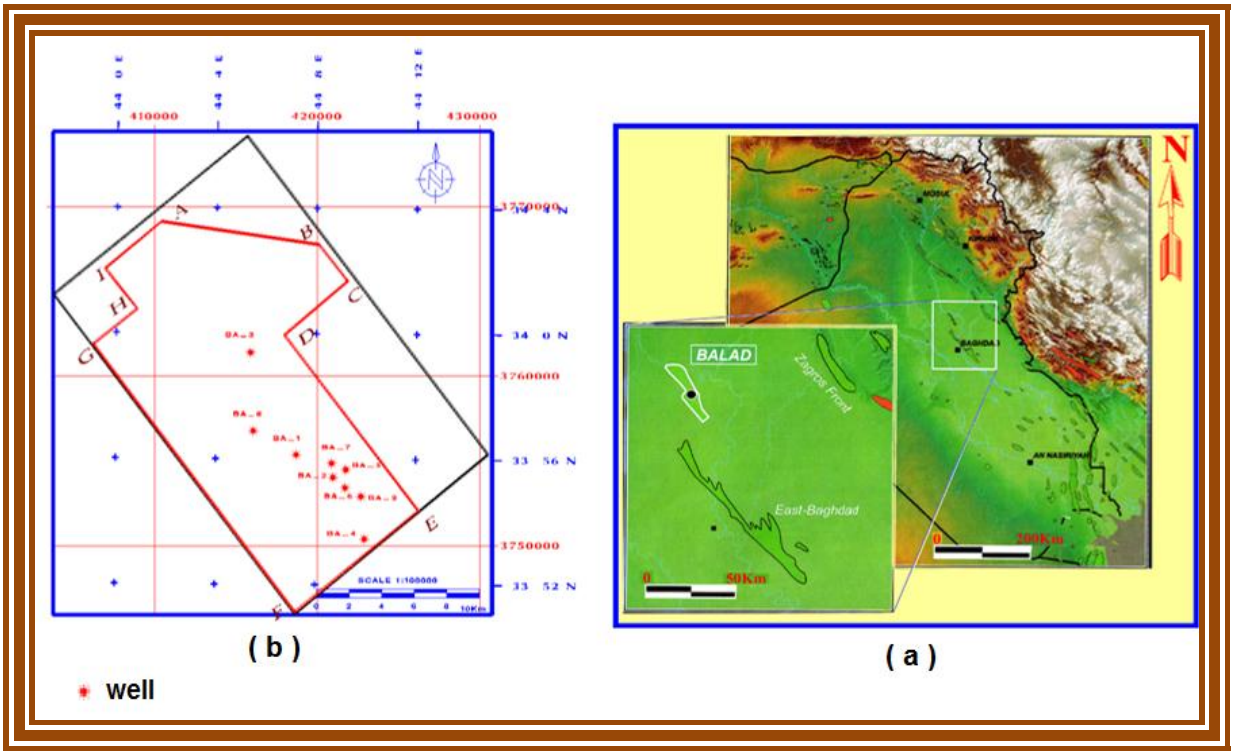

Figure 1- Location maps of the study area.

Theoretical background

Reflection coefficient

The role of seismic reflection gives more direct and detailed picture of the subsurface geological structures**.** The essence of seismic reflection technique is to measure the time taken for a seismic wave to travel from a source (at a known location near the surface) down into the ground where it is reflected back to the surface and then detected at a receiver which is also near the surface at a known position. This time is known as Two- Way-Travel time [2].

The ratio between reflected energy to incident energy is representing reflection coefficient [3], the successive reflection coefficients on the surfaces separating between layers (interfaces) are called the reflectivity function or reflection coefficient log. This log is derived from acoustic impedance log as shown in figure-2. The reflectivity function is earth property represents the geological information we are looking for [4].

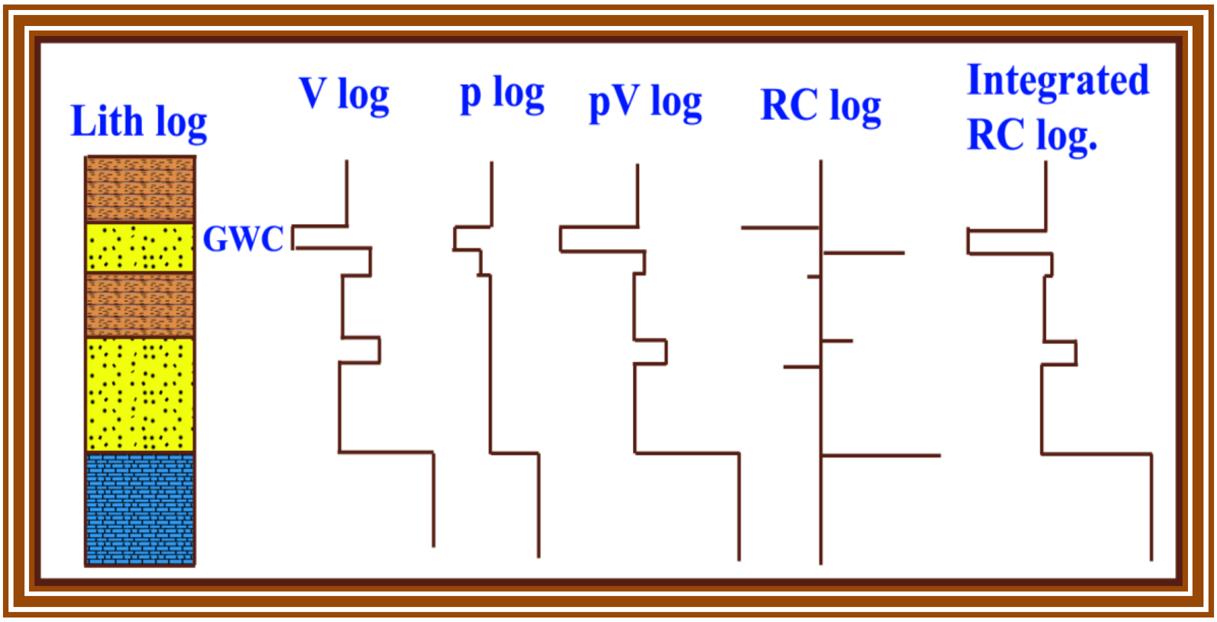

Figure 2- The steps of the reflection coefficient log derivation, after [4].

$$Rc = \frac{\mathrm{Ar}}{\mathrm{Ai}} = \frac{Z2 - Z1}{Z2 + Z1} \qquad \ldots \ldots (1)$$

$$\mathrm{Rc} = \frac{(V2\times \rho 2)-(V1\times \rho 1)}{(V2\times \rho 2)+(V1\times \rho 1)} \qquad \ldots \ldots (2)$$

Where:

Rc: is reflection coefficient.
Ai: is consequent amplitude of the incident energy.
Ar: is consequent amplitude of the reflected energy.

Reflection data processing

The aim of seismic data acquisition and processing is to deliver products that mimic cross-sections through the earth [5]. In order to do this, the correct amount and types of data must be acquired, processing applied to remove unwanted energy (such as multiples), and to place the required events in the correct location. At the same time, a balance needs to be struck between cost and timelines of data, while attaining also the important objectives of safe operations and doing no harm to the environment [6]

Interpretation and Attribute Analysis

Seismic interpretation is directed toward geological understanding of the subsurface geological picture, the dense data provided by 3D seismic offers more scope for defining the external geometry and internal architecture of reservoir bodies. The detailed 3D seismic map view is often more instructive than an individual section.

The faults determination is achieved according to the principle indications of faulting on seismic sections as described by [7]. They are the followings:

1. Discontinuities in reflections falling along an essentially liner pattern
2. Disclosures in tying reflections around loops.
3. Divergences in dip not related to stratigraphy.
4. Diffraction patterns, particularly those with vertices which line up in a manner consistent with local faulting.
5. Distortion or disappearance of reflections below suspected fault lines.

The seismic trace represents the variable function between the amplitude and time in the time domain. The Hilbert transform is a kind of filtering which does not affect the amplitude of the spectral component, but it causes changes in the phases of these components by 90° to obtain the imaginary part of the complex function that we get from knowledge of the real part which represents the conventional seismic section [8].

Faults Picking and Recognition

[8] has indicated that seismic attribute sections, especially the instantaneous phase section are very important for the distinction of reflector surfaces continuity termination because it does not depend on the reflection strength. Thus, instantaneous phase attributes technique is applied for all seismic sections in 3D volume. The faults were picked in all the area along each inline, cross lines and arbitrary lines. Each inline is used because it is normal on the general dip of reflectors. Thus, the fault is more distinct along the inline sections.

The instantaneous phase section shows that the study area to be affected by major normal fault which called Listric growth normal fault and its branches (Dendritic faults); it is interpreted as main major graben with variable width by approximately (3.5 to 4.0 km) on seismic sections and large displacements of all studied reflectors except the top Hartha reflector. Another small graben with small displacement is distinguished in the northeast of study area. Generally, the graben axes have northwest- southeast trends (approximately N 35˚ S) figure-3a & b.

The variance phase attribute technique is applied on seismic time slices for all study area of target reflectors. This type of attribute helps to distinguish the animation of faults and fractures that affected on the studied reflectors to draw their boundaries on maps. The fault boundaries map shows presence of shift and discontinuity for major graben boundary in the middle of study area, it was interpreted as Strike-Slip fault affecting study area and dividing the major graben to north and south parts figure-4a & b. Then minor tension faults have small displacements were picked, they locate in the south part of major graben and eastern shoulder.

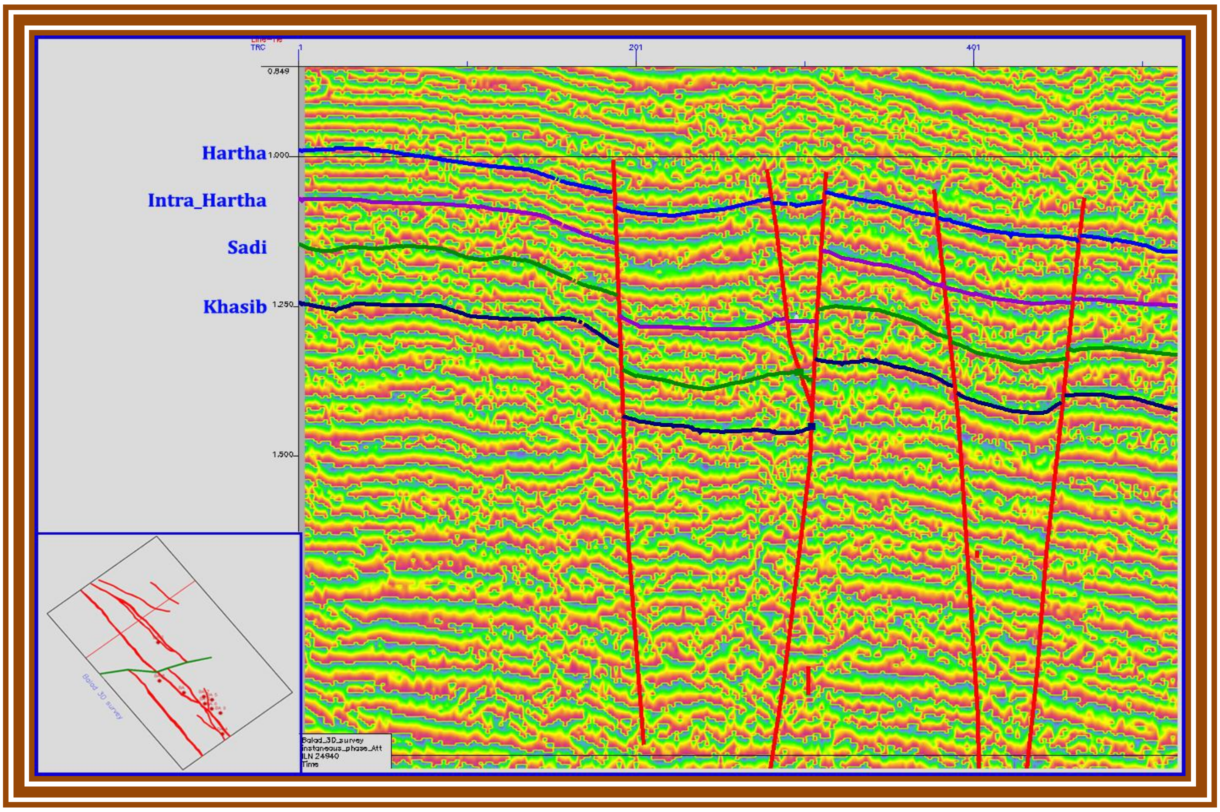

Figure 3a- Inline seismic section with instantaneous phase attributes shows the picked faults in the north part of study area.

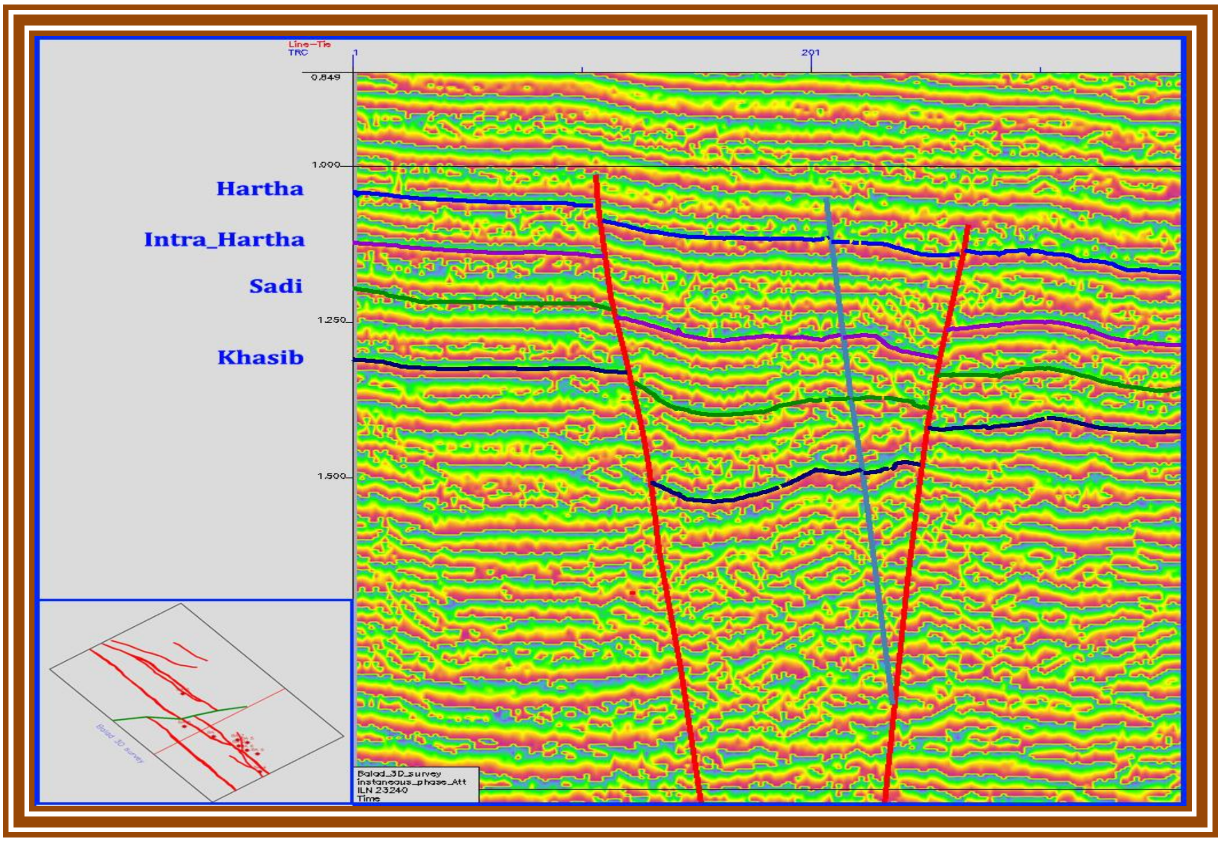

Figure-3b Inline seismic section with instantaneous phase attributes shows the picked faults in the south part of study area.

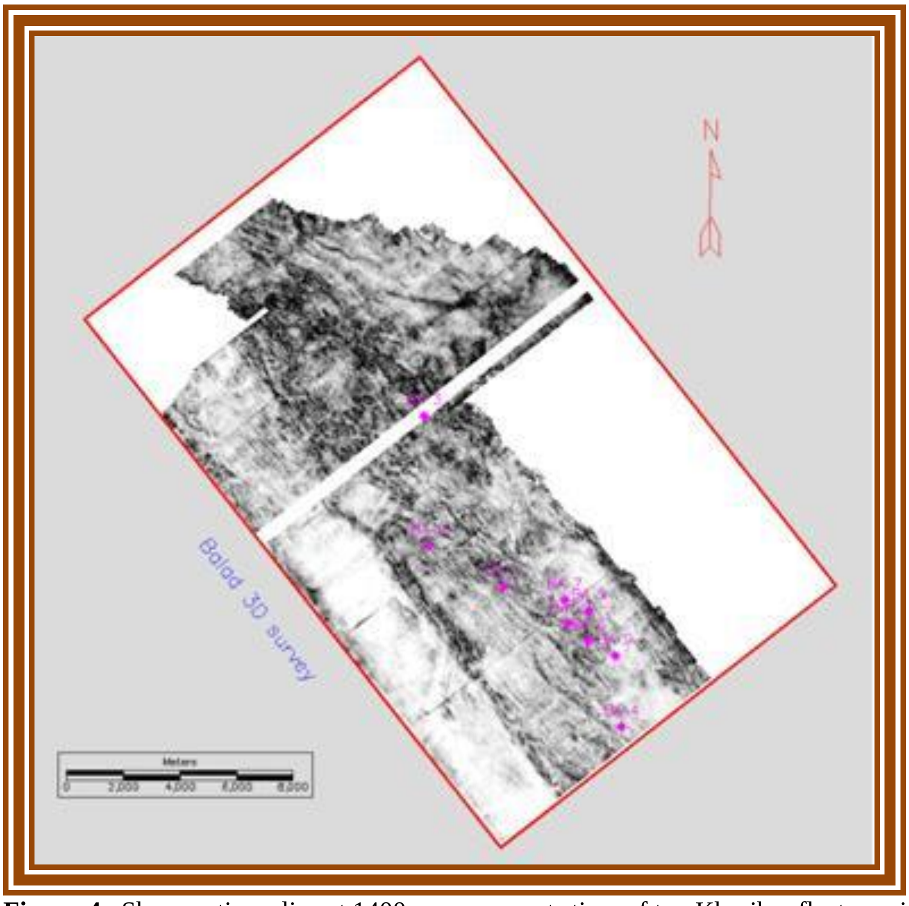

Figure-4a Shows a time slice at 1400 ms, represents time of top Khasib reflector without faults interpretation.

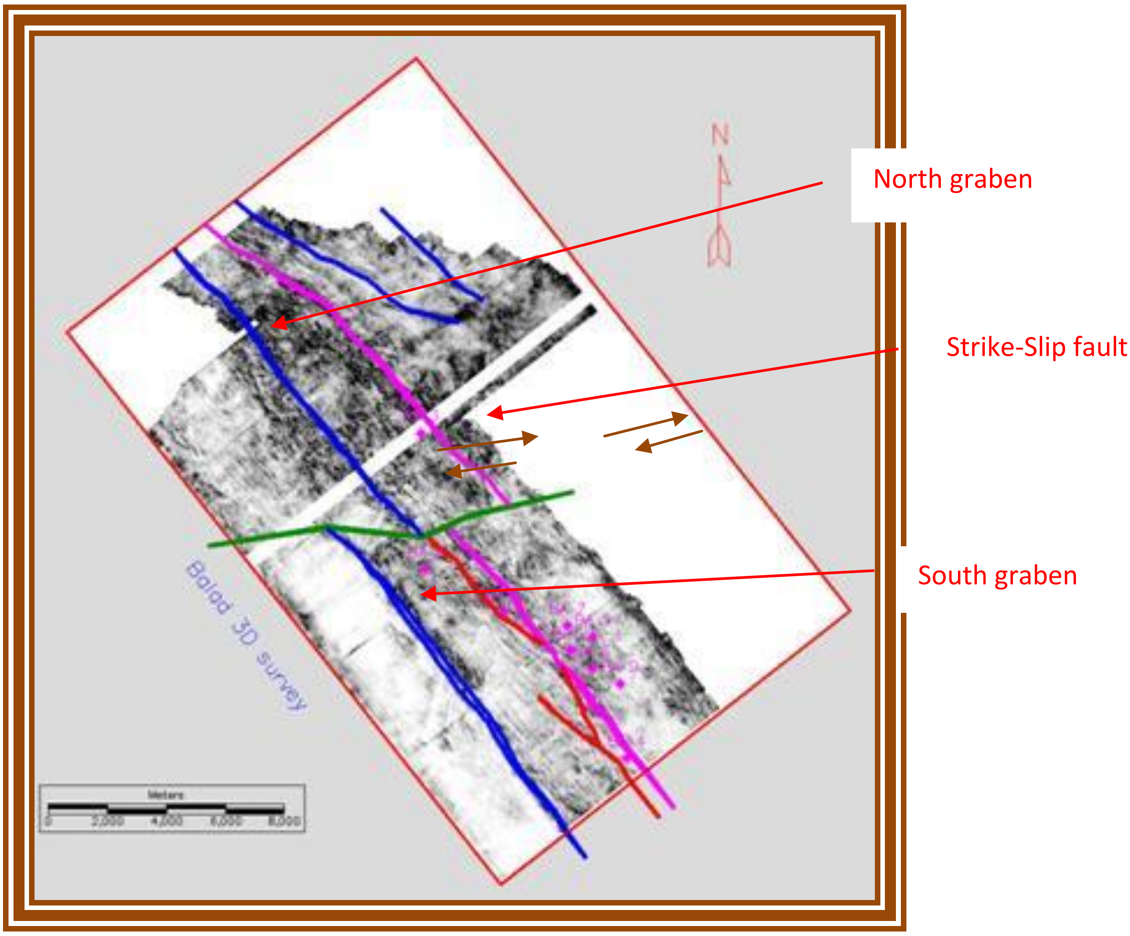

Figure 4b- Shows a time slice at 1400 ms, represents time of top Khasib reflector with faults interpretation.

Faults Interpretation

Based on interpretation of picked reflectors and formations thickness in the wells drilled in the Balad field, the orogenic movements of the mentioned faults can be divided as follows:

1-Stage of Listric growth normal fault:

According to seismic sections and well data, this type of normal faults develops due to increase in weight (thickness) of sediments which are variety at the head of the hanging wall comparing with thickness at foot wall where it almost constant and thinner [9].

The interpretation of seismic section shows that interval time of Hartha and Sadi reflectors is variable with presence of the on lap stratigraphy features inside the major graben area; this refers to the increase in the thickness of sediments to the south of the study area. While in the shoulders area, the interval time is less and almost fixed. On the other hand, the interval time of Khasib reflector is almost fixed and equitable both inside major graben and shoulders area figure-5.

The well data showed that thickness of the Hartha Formation was 460, 560, 439 and 436 meters respectively, of wells Ba_1, 3, 4 and 8 drilled inside major graben area, compared with the Hartha Formation thickness of 316, 306, 307 309 and 304 meters respectively of wells Ba_ 2, 5, 6, 7 and 9, which were drilled on the east shoulder of the study area. Additionally, the thickness of Sadi Formation in wells Ba_1 and 4 was also variable between 183 and 190 meters.

The Khasib thickness was similar in all wells, both within major graben area and on the east shoulder where it is 119 m in well Ba_9 and 114 meters in the well Ba_8.

This lead to Listric growth normal fault which begun during the deposition of Sadi and Hartha Formations as a result of gravitation force, which has occrued after the first stage of tectonic movements on upper Cretaceous Formations and the underlying layers [10].

2–Stage of Strike-Slip fault:

This fault was developed as a result of the rotation movements of Arabian plate due to the opening of the Red sea which tack place during the Oligocene age.

3– Stage of compression:

Separation of the Arabian Plate from the African continent led to collision between Arabian Plate with the Eurasian plate that occurred in the Oligocene age. This collision led to compressing of the Mesopotamia basin, shifting the old structural axes from the north-south to the northwest-southeast trend and in addition, tension faults were developed figure-6 [10].

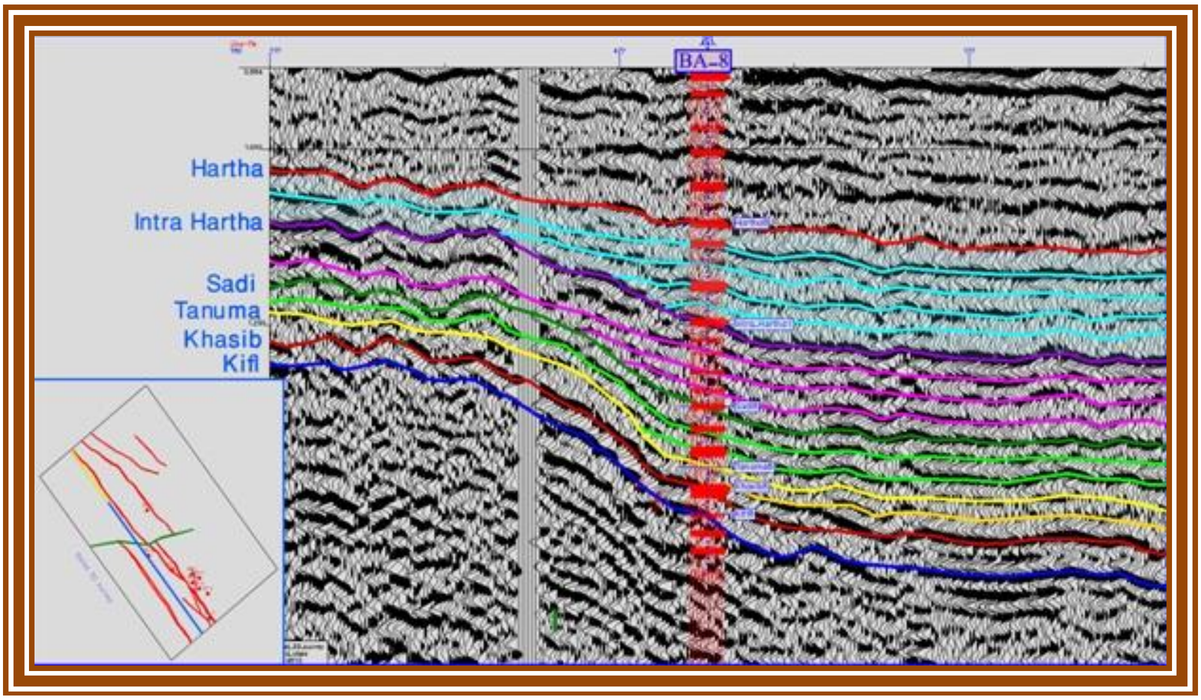

Figure-5- Cross-line seismic section passes in the south graben area illustrates on lap stratigraphy feature and the variable of the interval time of Hartha and Sadi to south of study area comparing with the fixed interval time of Khasib reflector.

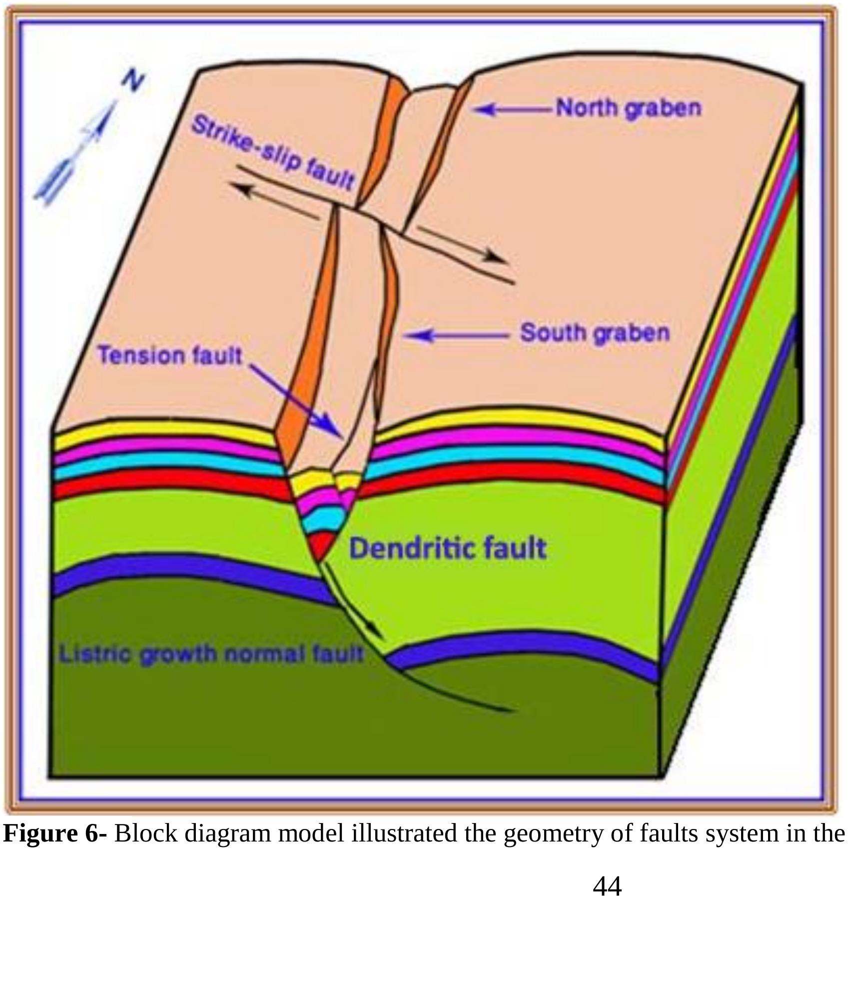

Figure 6- Block diagram model illustrated the geometry of faults system in the study area.

Conclusions

Based on the seismic interpretation given in this research, the following conclusions can be made:

1. A major graben was picked along study area on instantaneous phase sections. Also, a local graben picked in the northeast part of study area and formed a horst area with the major graben. These features extend in NW-SE trend. They affect Cretaceous rocks and underlying layers. Top Hartha reflector represents the end of fault effects.
2. The variance phase attribute was applied on time slices to follow the faults animation and termination. It showed shift and discontinuity of major graben faults in the middle of study area. These shift and discontinuity were interpreted as strike-slip fault with E-W trend. It cuts the major graben faults and separates the study area into two parts (south and north parts). In addition, secondary minor faults were shown and picked.
3. Based on the stratigraphy features in the seismic sections and well data drilled in the field, the type of normal faults that affected the study area was listric growth normal fault with branches (Dendritic faults).

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